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Experimental Study to Enhance the Performance of Heat Transfer in Fire Tube Boilers

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Abstract

This paper deals with experimental study which is a fixed the corrugated strip plate inside fire box tube (furnace duct), in order to enhanced the performance of heat transfer between the hot gases inside tubes and water outside the tube.As well as to prevent furnace walls by making the combustion hot gases is homogenous hot gases inside the furnace which is cases the high thermal stress. Upon the furnace wall. The results of experimental work gives good indications, this agreement enhance the heat transfer gives long life time and reduce the madding cost of the boiler.

List of Symbols

Symbol	Definition	Unit
A_s	Surface area	m^2
cp	Specific heat	Kj/Kg/K
g	Acceleration cost	m/s^2
h	Heat transfer coefficient	$w/m^2.C°$
k	Thermal conductivity	w/m.K
q_{nucl}	Amount of heat transfer	w/m^2
Q_F	Heat transfer by radiation	W
T_f	Film temperature	C°
T_w	Furnace wall temperature	C°
T_e	Hot gas temperature	C°
T_s	Surface temperature	C°
v	Kinematic viscosity	m^2/s
μ	Dynamic viscosity	Kg/m.s
σ_r	Stephan – Polsman constant	$w/m^2.k^4$
ε	Emissivity from surface	
ρ	Density	Kg/m^3
Gr	Grashof Number	
Pr	Prandtle Number	
Nu	Nusselt Number	
Re	Renold's Number	

INTRODUCTION

Boiler is a pressure vessel designed to transfer heat (produced by combustion) to a fluid. The definition expanded to include transfer of heat from electrical resistance elements to the fluid, or by direct action of electrodes on the fluid. In most boilers, the fluid is usually water in the form of liquid or steam. The fire box or combustion chamber of boilers is called furnace.

The boiler applies to a device for generating:

1. Steam for power, processing or heating purposes.
2. Hot water for heating purposes or hot water supply.

The materials of boilers are cast-iron, steel, aluminum or copper carbon steel. Boilers are designed to transmit heat from an external combustion source (usually fuel combustion) to fluid contained within the boiler itself.
The working fluid is water or steam. The steam or hot water must be delivered in desired conditions with respect to pressure, temperature and quality.
The heat output to rate (steam or hot water generated per hour) depends upon the following factors:

1. Extent of combustion of the furnace fuel.
2. Extent of heating surface.
3. Distribution of the heating surface prime (radiant) and secondary (convection) areas.
4. Circulation of steam or water and combustion products.

Study deal with experimental work to improve the efficiency of boiler. To enhance the performance of heat transfer in fire tube steam boilers. Fixed the corrected strip below element inside the boilers furnace. These strip elements increase the heat transfer coefficient increase surface area heating and prevent the furnace walls from high temperature of combustion and its gives the boiler long time life boilers. The original shell boiler (tea kettle type) was first improved by passing the hot gases through the inside of tube located within the shell. This modification marked the beginning of the tube boiler. The efficiency of the fire tube boiler is much higher than that of the simple shell boiler because heat is absorbed by the tubes as well as shell. Boiler output capacity is increased for the same overall dimension, and fuel combustion is reduced. Figure (1) shows that in these boiler the hot gases inside the tubes and the water surrounded the tubes. These boilers used for heating systems, for industrial processes, steam or as portable or mobile. All approved fire tube boilers are constructed in accordance with the ASME boiler code.

Fig (1) *Fire – tube boiler*

1. Steam.
2. Design of fire chamber with 1st pass, 2nd pass and 3rd pass.
3. Design of fire chamber with 1st pass, 2nd pass and 3rd pass.
4. Design of fire chamber with 1st pass, 2nd pass and 3rd pass.
5. Front door.
6. sight glass.
7. Wet back.
8. manhole and hand hole.
9. Insulator (glass wool).
10. Steam separator.
11. Burner.

It is furnace duct with the combustion process take place in it. The fuel is burned under the front portion of shell. The product of combustion sweep over the fuel length to the rear of the setting where they turn and enter the first tube pass travel to the front smoke box, reverse direction and travel through the second tube pass the rear gas outlet.

It is necessary to increase furnace column more than boiler structural limitation in this work used corrected strip element inside the fire box (furnace) to increase the heat transfer from the hot gas to the water surrounded, as well as to prevent the furnace wall from high temperature. Figure (2)

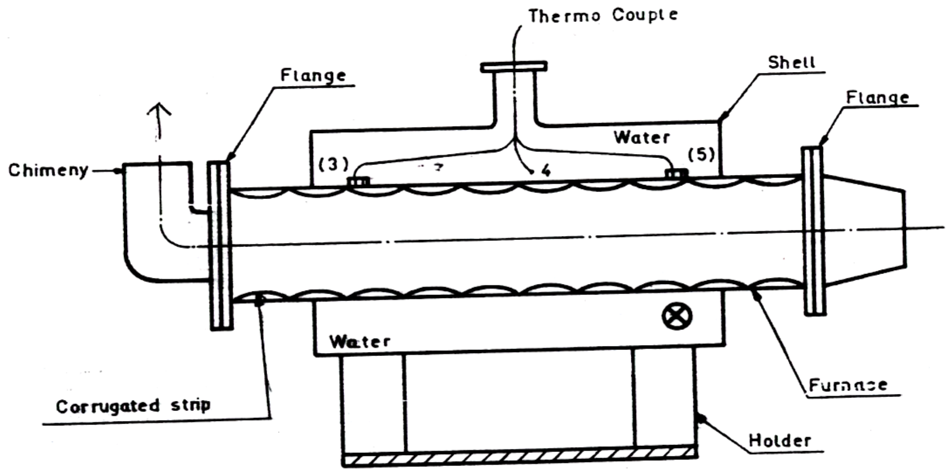


Fig (2): *Furnace with corrected strip element*

Experimental Work

The aim of these experiments is to determine the heat transfer with the corrugate strip inside fire tube. The experimental system as shown in figure (3) consist of:

1. Horizontal cylinder form (shell) is made of cylindrical section. The outer diameter of shell (60 cm). Thickness of shell (1.4 cm), the length of the shell is (100 cm). Two holes are in both sides of shell , each one (30 cm diameter), the shell fills with water.
2. Fire box (furnace), it is a horizontal tube (30 cm) diameter made of carbon steel, the eight corrugated strips sheet plate are made of carbon steel fixed in side surface of the fire box. The shape and specification of plates are shown in figure (3).
3. The boiler shell is made of cylindrical sections or courses which may be straight or tapered. A stem dome is placed on the boiler shell top to collect steam for entry the throttle pipe.
4. The boiler tubes are placed in the cylindrical boiler shell and outer into tube sheets at fire box and smoke box. They are surrounded by water and combustion gases, 30 cm diameter, made of carbon steel, eight corrugated strips sheet plate are fixed inside furnace surface.

An analysis of furnace heat transfer is extremely complex and not subject theoretical computation. It is necessary, however, to predict the furnace outlet temperature because the design of the remainder of the heat generating unit depends upon this figure. The temperature varies throughout the furnace as shown in figure (2). The furnace geometry, flame shape and length, wall surface characteristics, flame emissivity, and surface clean less all effect the heat transfer of furnace.

It has been found that furnace exit gas temperature correlates with the absorbing surface in a logarithmic function. The present of corrected strips inside the furnace, causes the turbulent flames with a high degree of emissivity. An increasing in the firing rate will results in higher temperature.

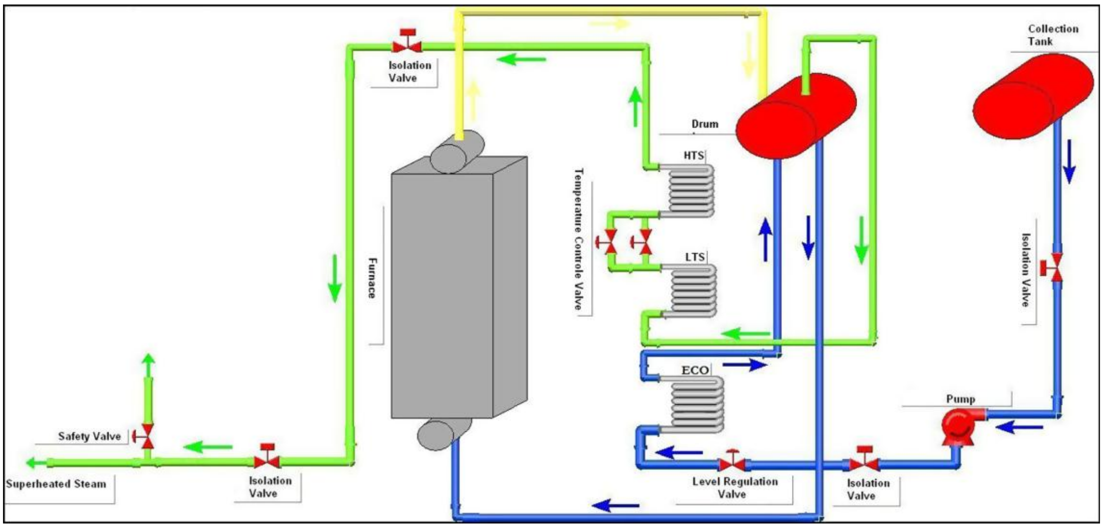


Fig (3): *Details of laboratory system*

Mathematical Model

Calculation of Heat Transfer Coefficient with Corrugated Strips (Overall)

To be calculate heat transfer coefficient (h_i) inside fire tube use this relation:

$$Nu = 0.134\left(\mathrm{Re}^{0.681}.\mathrm{Pr}^{0.33}\right)\left[\frac{p_f - t_f}{L_f}\right]^{0.2}\left[\frac{p_f}{t_f}\right]^{0.1134} \quad \ldots\ldots\ldots\ldots (1)$$

Where (p_f, l_f, t_f) as shown in figure (4-1)

$$hi = \frac{Nu.k}{d_i} \quad \ldots\ldots\ldots\ldots (2)$$

To calculate heat transfer coefficient (h_o) outside the fire tube use:

$$Nu = 0.135\,\mathrm{Re}^{\frac{1}{3}} \quad \ldots\ldots\ldots\ldots (3)$$

$$h_o = \frac{Nu.k}{d_o} \quad \ldots\ldots\ldots\ldots (4)$$

We find all physical properties of (T_f) where:

$$T_f = \frac{T_{sur} + T_s}{2} \quad \ldots\ldots\ldots\ldots (5)$$

The overall heat transfer coefficient (U) is given as:

$$U = \frac{1}{\sum R} \quad \ldots\ldots\ldots\ldots (6)$$

$$U = \frac{1}{\frac{1}{h_i} + \frac{\ln\frac{r_o}{r_i}}{2\pi KL}.A_i + \frac{d_i}{h_o\,d_o} + ff_i + ff_o} \quad \ldots\ldots\ldots\ldots (7)$$

Where:

ff_i = Fouling factor inside fire tube = 0.001

ff_o = Fouling factor outside fire tube = 0.005

3-2 Calculate heat transfer coefficient (overall) without corrugate strips.
Calculate heat transfer coefficient (hi) from:

$$Nu = 0.023 \mathrm{Re}^n \mathrm{Pr}^m \quad \text{………………………………..} \ (8)$$

n=0.8 , m=0.3
Calculate heat transfer coefficient (ho) from:

$$Nu = 0.0135 \mathrm{Re}^{\frac{1}{3}} \quad \text{……………………………………..} \ (9)$$

3-3 The heat transfer from burner gases to fire tube sides

$$Q_F = As\, \varepsilon_f\, \varepsilon_w\, \sigma_r \left(T_g^4 - T_w^4\right) \quad \text{…………………….. (10)}$$

$$Tg = Te + 150 \quad \text{…………………………………….. (10-a) without strips}$$

$$Tg = Te + 210 \quad \text{…………………………………….. (10-b) with strips}$$

$$q_{nucl} = \mu_f\, h_{fg} \left[\frac{g\left(\rho_L - \rho_V\right)}{\sigma}\right]^{\frac{1}{2}} \left[\frac{CP_L\left(T_s - T_{sat}\right)}{C_{sf}\, h_{fg}\, P_r^n}\right]^3 \quad \text{……………… (11)}$$

Case Study
The following specifications of fire tube boiler are furnace material (carbon steel 516 Gr70) length = 10 cm.
OD = 30 cm, ID = 28 cm
Number of strips = 8
Temperature of hot gases = 450 °C
Temperature of outer surface of furnace = 120 °C
Temperature of saturated water = 100 °C
To calculate heat transfer coefficient (h_i) with strips:
Ai = 0.879 m^2
Ao = 0.9452 m^2
Sub in equation (1) where
P_f = 0.196 m
L_f = 0.03 m
$t_f = 0.8 \times 10^{-2}$ m
After sub the above results in equation (7) to calculate the overall heat transfer coefficient with corrugated strips.

- To calculate heat transfer coefficient without corrugated strips (hi).
  At temperature of hot gases = 450 °C we find properties of hot gases
  Re = 42.39×10^3
  At this range the flow is turbulent
  Nu = 10.18
  hi = 11.36 w/m^2 °C
- To calculate heat transfer (ho) outside fire tube (ho)
  Nu = 3.8×10^3
  ho = 760 w/m^2 °C
- Overall heat transfer coefficient without strips

$U_{overall} = 11.43$ w/m^2 °C

After comparing between the above value and this value we find it less than from overall heat transfer coefficient with strips.

B. Calculate amount of heat transfer from hot gases to surface of furnace.
After sub the following data in equation (3-10-a) and (3-10-b) for many times table (4-1) results.
$\varepsilon_f = 0.3$
$\sigma_r = 5.8 \times 10^{-8}$
$\varepsilon_\omega = 0.5$
As = 0.879 m^2
C. To calculate amount of heat transfer wanted to generating steam use equation (3-11)
Where:
N = 1
$\sigma = 0.0598$
$C_{PL} = 4217$ Kj/Kg. K
We find
$q_{nucl} = 3.5 \times 10^6$ W/m^2

This mount calculates per unit area and it increase with surface roughness which it because increase heat transfer coefficient from hot gases to water wanted to vaporization.

Time (min)	**Q_f with strips (KW)**	**Q_f without strips (KW)**
0	1.24	0.912
25	1.33	0.887
35	1.47	0.964
60	1.735	1.173
65	2.35	1.593
70	2.509	1.8

Results and Discussions

Results of Experimental Test (with corrugated strips)

The results are shown in the following figures. There are four tests for fire box with corrugated strips, the results for these tests show temperature distribution outside the fire box, also water temperature and hot gases where (T_1) represents hot gas temperature, (T_5) represent furnace temperature near burner, (T_3) represent furnace surface temperature near the end of furnace and (T_4) represent water temperature surrounding furnace, which is wanted to evaporation.

Temperature was measured each (15 minutes) which is rise with time, also it rises from test to other because enhanced fire flame gradually. Figure (5-1) shows temperature distribution on the surface of fire tube and chimney, and also water temperature surrounding furnace at first run. Figure (5-2) shows the temperature distribution at second run. The relationship between the temperature with time is increase gradually were (T_1) increased with time of operation because hot gases at high temperature and velocity belong the fire tube. (T_5) greater than (T_1) because it nearest from the burner and beginning combustion inside furnace. (T_3) less than (T_5) because it measured at other end of burner. The furnace temperature decrease each farmer than the other end of hot gases because the absorption a lot of heat from furnace warm and for water surrounded furnace.

Figure (5-2) show the temperature distribution at second run, the relationship between temperature with time is increase gradually where (T_1) increase with time of operation because hot gases at high temperature and velocity along the fire tube. (T_5) greater than (T_1) because it nearest from burner and begging combustion inside furnace. (T_3) less than (T_5) because it measured at other end of burner. The furnace temperature decrease each farmer than the other end of hot gases because absorption a lot of heat from furnace wall and for water surrounded furnace.

(T_4) measured water temperature which is wanted to evaporate it which is increase until reach saturation temperature at this degree the steam generating.

At the same figure (T_4) decrease after (30 minutes) because adding cold water for usual that cause decreasing in temperature and after few minutes water temperature increase until reach saturation degree.

At third run figure (5-3) show increase in temperature distribution more than the first run and second run because a homogenously of burner flame and enhance performance for furnace. The increasing of outside furnace (T_3, T_5) because homogenous flame with corrugated strips fixed inside furnace this strip cause turbulent flow in got gases which is cause a homogenous combustion and equality in temperature distribution inside the furnace. The turbulent flow inside fire box increase the heat transfer coefficient from furnace to water evaporation. The equality temperature distribution inside furnace tube prevent furnace wall from high thermal stress which it cause cracks inside furnace wall.

Figure (5-11) shows the increasing in (T_1, T_3, T_4, T_5) and enhanced from test to other where heat are generating after (45 minutes) from system generation.

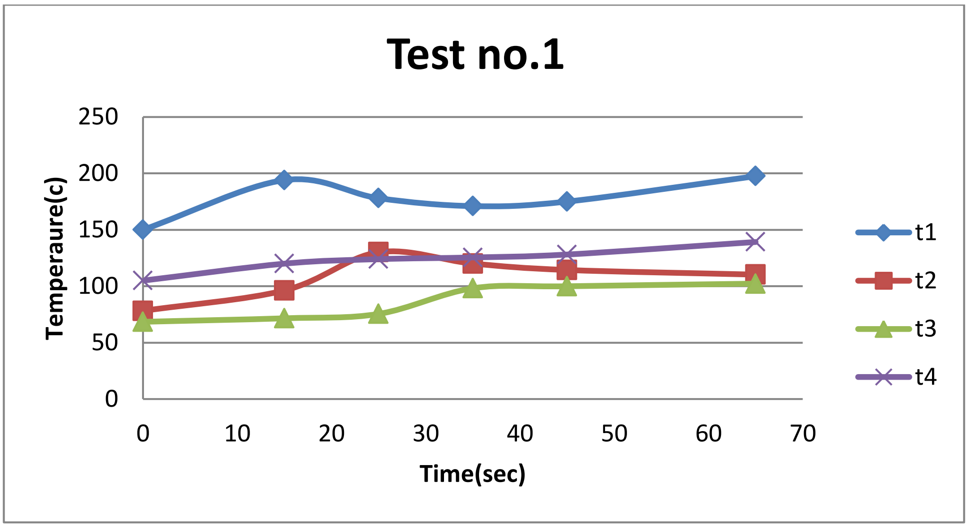
Results for Experimental Tests (Without Corrugated Strips)

There are two tests for system after reales curригated strips, these tests (5-5, 5-6) we show homogenous reading temperature with time because uncontrolling or gas flame and inequality in temperature distribution (T_1, T_3, T_4, T_5) and show (T_1) is greater than from tests with curragated strips because increasing in hot gases temperature from furnace and (T_3) is greater than (T_5) because laminar flow for hot gases and non lates gases flow inside fire tube. (T_4) is water temperature wanted to evaporation which is less than from currigated strips because reals absorption heat from furnace wall that cause decreasing in overall heat transfer coefficient and laminar flow in both figure (4-5, 5-6). The temperature distribution fluctuating and inequality.

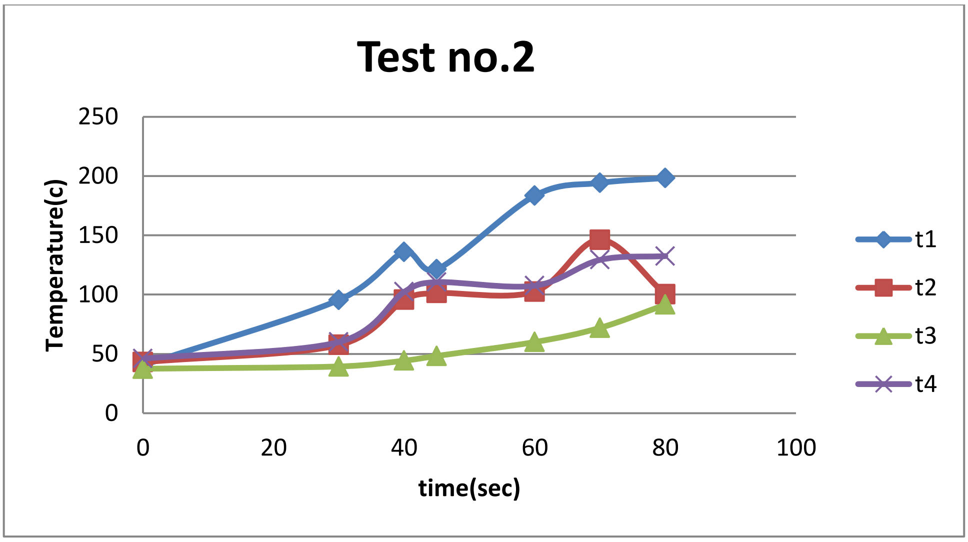
Theoretical results gives good indication for increasing amount of heat transfer from burner gas inside furnace to water evaporating in both cases with currigated strips and without it, the curragated strips inside fire tube make increasing overall heat transfer coefficient.

Figure (5-7) explain heat transfer with curragated strips and without it, where the amount of heat transfer greater than without curragated strips.

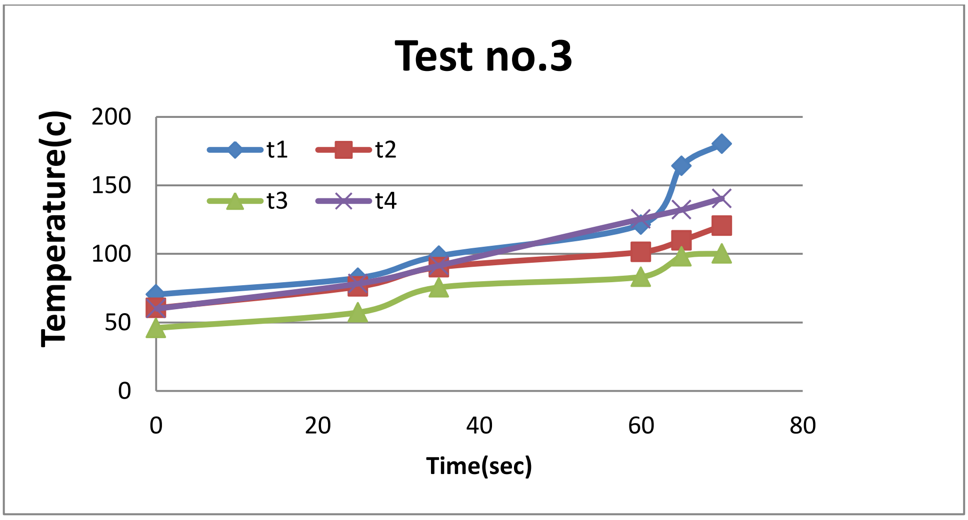
This strip gives minimum loss heat and less costs of maintenance for boiler and gives good fuel consumption and enhanced the performance of boiler.



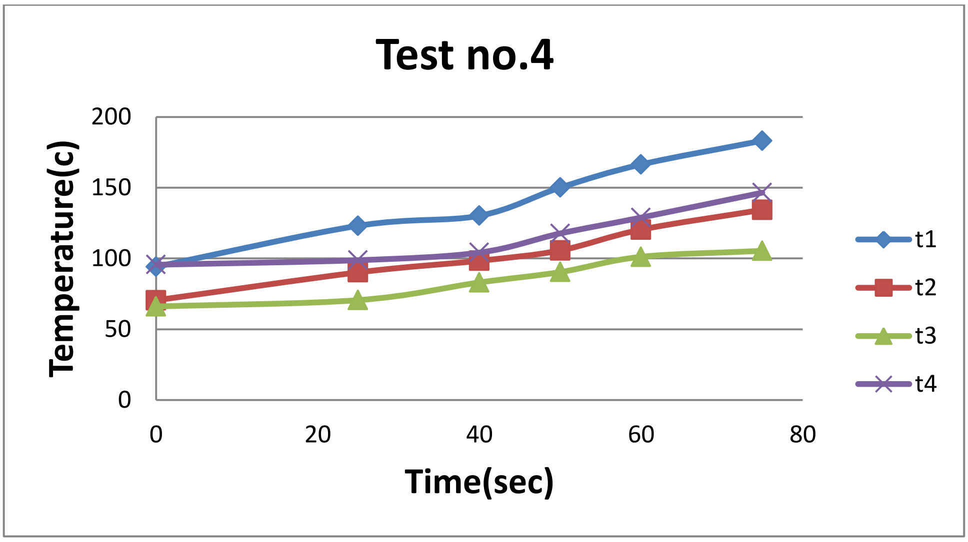
Fig(5-1) *relation between time and temperature for first run*



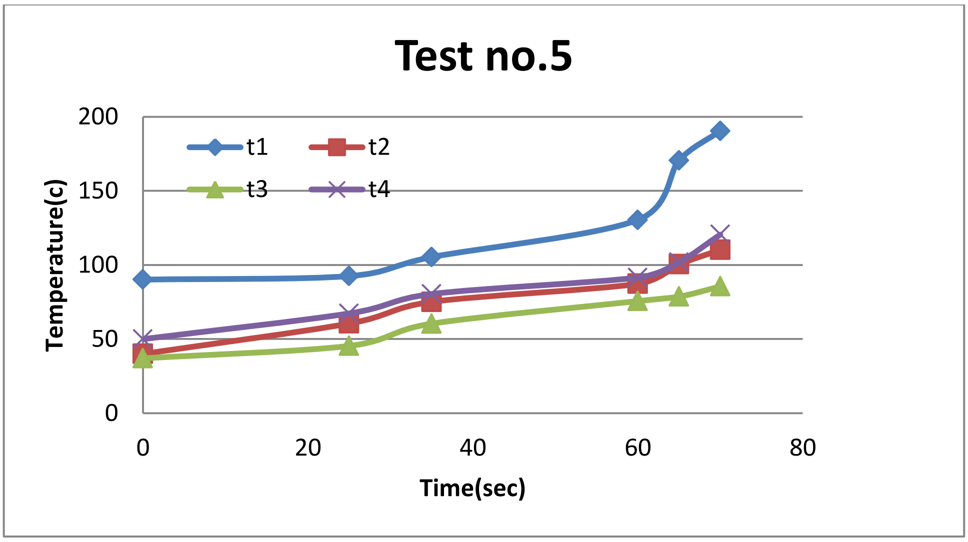
Fig(5-2) *relation between time and temperature for second run*



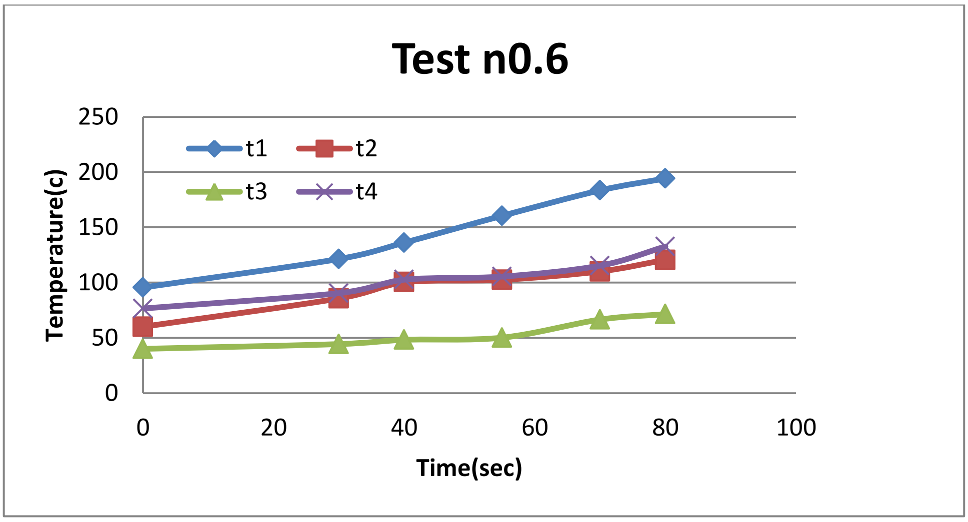
Fig(5-3) *relation between time and temperature for third run*



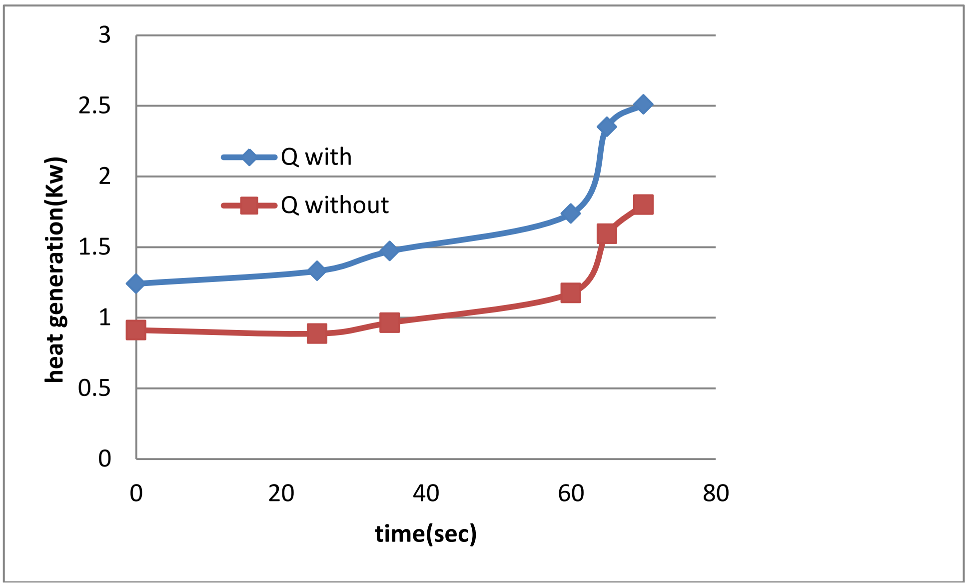
Fig(5-4) *relation between time and temperature for fourth run*



Fig(5-5) *relation between time and temperature for fifth run*



Fig(5-6) *relation between time and temperature for sixth run*



***Fig(5-7)** relation between time and heat generation inside the furnace*

CONCLUSIONS

1. Curragated strips inside fire tube make turbulent flow which cause a homogenous in hot gases.
2. Temperature distribution is equal inside furnace.
3. Thermal stresses are decreasing inside furnace wall which prevent cracks on wall (furnace) where temperature reaches (800 °C) inside furnace.
4. Decreasing maintenance costs.
5. Have long life operation for boiler.
6. Decreasing amount of fuel wanted to generate steam which compare with the other boilers. The amount of heat transfer from furnace to water is more than (1.5 one) from the boiler without corrugated strips.

Recommendations

1. We recommend fixed corrugated strips inside the tube boilers which it designed in industrial company.
2. We recommend fixed helical strips inside the tube boilers to increase the efficiency of heat combustion and enhanced the performance of boilers.

This boilers gives minimum maintenance costs and long life operation and high efficiency.

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